Classification of Research Results to Support Knowledge and Technology Transfer into Corporate Product Engineering

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Abstract: Research develops cutting-edge knowledge and technologies. Corporate engineers use these research results as input for their engineering activities. In literature, research results are classified by discipline and technologies following technology readiness levels. Here, we present a research results classification model based on the technology readiness levels that allow the allocation of any result from engineering research. We anticipate our results to be a starting point for developing targeted design support for the more efficient use of research results in corporate product engineering.

Keywords: Design Management, Technology Transfer, Product Development, Research Classification, Co-Design

1 Introduction

Humanoid robots advanced and introduced by Boston Dynamics (Bora, 2018), the natural language assistant Siri advanced and introduced by Apple as part of the iPhone (Giffin, 2021; International, Sri, 2021; Wardini, 2022), and EUV (extreme ultraviolet) lasers for the production of microchips advanced and introduced by Trumpf and Zeiss in cooperation with Fraunhofer (Fraunhofer-Gesellschaft, 2020) are three prominent examples of highly complex but successful new products. All these three examples have one thing in common. The development of these systems started within research. The companies introducing them did cooperate with research facilities or took research results as the starting point for the engineering activities. Universities and other research facilities continuously push the limits of knowledge and technology. Thereby, research produces valuable input for developing new systems and products in corporate product engineering. These developments are valuable references for companies on the market to innovate and prosper in the competition (EFI – Commission of Experts for Research and Innovation, 2022; Frank et al., 2007; Kleiner-Schaefer and Schaefer, 2022). Due to the increasing complexity of the systems under consideration, companies depend on inspiration to evolve their offers. Combined with the challenges of the time, often only the collaboration of industry and research can provide solutions, ultimately meeting the needs of society (Frank et al., 2007). However, integrating and applying research results into corporate engineering is still challenging (Kempf et al., 2023c). To address these challenges, the goal of this contribution is to investigate research results and their characteristics as input for engineering activities in corporate product engineering, resulting in a classification model for different types of research results.

2 References in Product Engineering

Engineers reuse already existing knowledge and designs to reduce development costs and time, and get more design flexibility (Eckert et al., 2004; Iyer et al., 2005). The literature provides various approaches to describe product engineering based on references (Albers et al., 2015; Hatchuel and Weil, 2003; Maher and Gomez de Silva Garza, 1997). With the model of SGE - System Generation Engineering (formerly known as the model of PGE - Product Generation Engineering), Albers et al. (2015) provide a model that can be used to describe the development of any new system (product) as a new system generation based on a reference system. As illustrated in Figure 1, the reference system collects all elements that serve as *"the basis and starting point for the development of the new product generation"* and calls them reference system elements (RSE) (Albers et al., 2019).

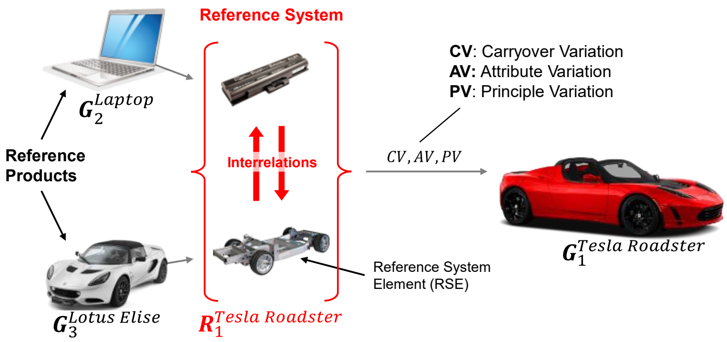

Figure 1. The reference system within the model of SGE - System Generation Engineering (Albers et al., 2019)

Reference system elements *"originate from already existing or already planned socio-technical systems and the associated documentation"* (Albers et al., 2019). Here, the most important sources for RSEs are previous and other projects known to the engineers (Ahmed, 2003; Shahin et al., 1999). Additionally, many other sources are possible (e.g., suppliers, clients, competitors, consultants, government, research institutes, conferences, etc.) (Albers et al., 2019; Hajialibeigi, 2021; Kempf et al., 2023a). With this, research is a source for RSEs of particular interest. To overcome today's big societal and technological challenges (e.g., in the fields of energy, climate, demographic change, etc.), a collaboration of industry and research is essential (Frank et al., 2007). Besides these grand challenges, RSEs from research offer many benefits for corporate product engineering. Kempf et al. (2023b) systematically analyzed the reasons for using RSEs from research from a company perspective. E.g., being cutting-edge knowledge or technologies can provide a competitive advantage or offer new input to approach design challenges in a new way. (EFI – Commission of Experts for Research and Innovation, 2022; Frank et al., 2007; Kempf et al., 2023b; Kleiner-Schaefer and Schaefer, 2022).

Research produces a wide range of different types of results and output: (Bakouros and Samara, 2010) list *"scientific and technological information […], equipment and instrumentation […], skills or human capital […], networks of scientific and technological capabilities […], and prototypes for new products and processes"* as examples for results. The (European Commission, 2010) lists *"audio visual recordings, computer software and databases, technical drawings, designs or working models, major works in production or exhibition and/or award-winning design, patents or plant breeding rights, major art works, policy documents or briefs, research or technical reports, legal cases, maps, translations or editing of major works within academic standards"* as a selection of possible research result types. These results are usually clustered regarding their subject area (Gautam Pitambar, 2019). (Lee and Lee, 2014) introduce a classification system for research results in the field of sustainability based on the technology readiness levels (TRLs). Initially, (Mankins, 1995) introduced the technology readiness levels to support the assessment of the maturity of technologies for NASA space technologies. Mankins distinguishes nine different readiness levels, as illustrated in Figure 2.

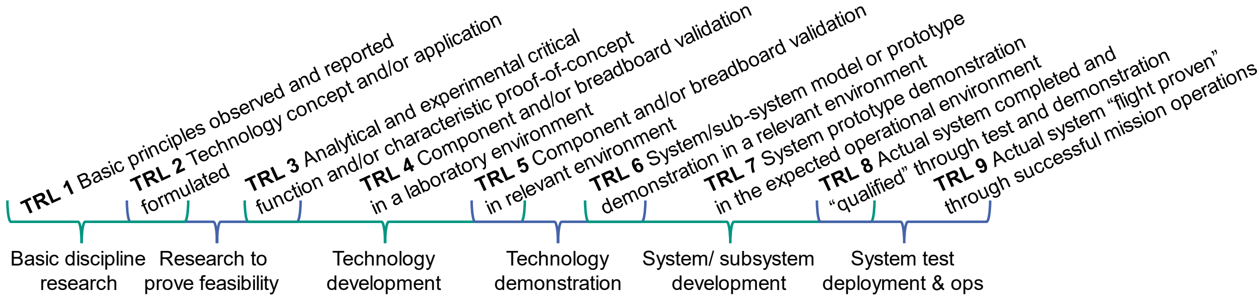

Figure 2. Technology readiness levels (TRLs) (Mankins, 2009)

Similarly, the Expert Commission Engineering Science distinguishes research regarding the time horizon it takes to influence society. They consider research by short-, mid-, and long-term influence (Bauernhansl and Nestler, 2015). As part of the Commission, Albers (2018) follows this classification of research. Research with potential social influence, in the long run, is usually done by universities and other research facilities only. In contrast, the participation of companies and their research departments increases as the time scope for social influence decreases (Albers, 2018).

3 Research Profile

As shown in the previous chapter, the scientific literature offers possibilities for bibliographic classification of research results and maturity categorization of technologies. However, in a previous study, we noticed that different barriers corporate engineers have to face when working with research results as RSEs are linked to specific types of research results

(Kempf et al., 2023b). To enable design research to support the usage of research results as RSEs in corporate engineering in a targeted manner, an overview of the different types and the possibility of classifying them are necessary. The bibliographic classification does not pay respect to the specifics of different results within a category, and the concept of technology readiness levels is too focused on technologies only.

Thus, the main goal of this contribution is the design of a classification model for results generated in research. Therefore, we first need to identify the various types of results generated in research.

To reach these goals, we formulated the following two research questions to structure this submission:

- RQ1: What types of results are generated in research?
- RQ2: How can the results from research be sorted in a classification model?

To summarize our findings, we provide a research result classification model to enable an overview of the various types of research results and their specifics. The findings of this contribution form the basis for further design research and enable the development of specific design support that helps integrate different types of research results into corporate product engineering.

3.1 Research Approach

To answer the research questions formulated above, we followed a four-step approach. First, we conducted two systematic literature reviews to get an overview of the literature regarding types of research results and their classification models within the Scopus database (Chapter 4.1). Therefore, we used the following search string (SSI) to identify different types of research results:

SSI: TITLE ((type OR kind* OR form*) AND ("research* result*" OR "research* output*" OR "scien* result*" OR "scien* output*")) OR KEY ((type* OR kind* OR form*) AND ("research* result*" OR "research* output*" OR "scien* result*" OR "scien* output*"))*

To identify classification models, we used the following search string (SSII):

SSII: TITLE (("research result" OR "research output" OR "research finding" OR "scientific result" OR "scientific output" OR "scientific finding") AND (classification OR categorization OR categorisation OR readiness OR maturity)) OR KEY (("research result" OR "research output" OR "research finding" OR "scientific result" OR "scientific output" OR "scientific finding") AND (classification OR categorization OR categorisation OR readiness OR maturity)) OR TITLE-ABS-KEY(("research result" OR "research output" OR "research finding" OR "scientific result" OR "scientific output" OR "scientific finding") AND (classification OR categorization OR categorisation) AND (readiness OR maturity))

For both searches, we limited the results to English journal and conference proceeding publications in the subject areas of engineering, social sciences, and business, management and accounting. To get more focused results, we only searched within the titles and keywords to identify the different types of research results (SSI). Terms like results, type, etc., are widely used in abstracts, leading to a significant share of unrelated publications. For the search of classification models (SSII), we used a more specific combination of the search terms to search the abstracts, too. To identify relevant publications for both searches, we followed a five-step process. First, we eliminated duplicates before excluding irrelevant publications based on the titles in the second, the abstract in the third, and the full texts in the fourth step. Within the search for different result types, we excluded publications, considering scientific publications such as journal and conference proceeding publications as the only results. In the final step, we conducted a forward and backward search.

In the second step, we complemented the findings of the systematic literature review with the common practice of research result classification in the German research community (Chapter 4.2). Based on these findings, we synthesized our research results classification model in the third step (Chapter 5.1). Finally, we used an interview study to gather the research results of four researchers within different engineering disciplines for an initial validation of our classification model (Chapter 5.2).

4 Different Types of Research Results and Their Classification

In the following, we first present the systematic literature review results in Chapter 4.1. Figure 3 provides an overview of the process and results. We present the various types of research results we identified in Chapter 4.1.1 and classification models in Chapter 4.1.2.

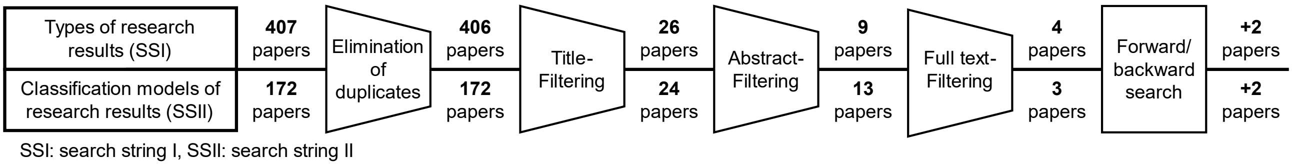

Figure 3. Systematic literature review - results of filtering and selection process

Finally, we present the classification models the research community uses in Chapter 4.2.

4.1 Classification Models Described in the Literature

4.1.1 Types of Research Results Described in the Literature

The primary type of research results are scientific publications such as journal publications and conference proceedings. In Table 1, we provide an overview of additional types of research results distinguished by the publications we identified in the systematic literature review.

Table 1. Different types of research results described in the literature

Literature	Types of research results
"Academic Liaison Offices vs. Technology Transfer Units: Could they form a new joint mechanism towards the exploration of Academic/Research results?" (Bakouros and Samara, 2010)	"among others: scientific and technological information […], equipment and instrumentation […], skills or human capital (embodied in students and faculty members), networks of scientific and technological capabilities […], and prototypes for new products and processes"
"Analysing the economic payoffs from basic research" (David et al., 1992)*	"e.g., scientific instruments or training of scientists and engineers"
	Educated and trained scientists and social networks for information diffusion
"Assessing Europe's university-based research: expert group on assessment of university-based research" (European Commission, 2010)*	"[…] inter alia, audio visual recordings, computer software and databases, technical drawings, designs or working models, major works in production or exhibition and/or award-winning design, patents or plant breeding rights, major art works, policy documents or briefs, research or technical reports, legal cases, maps, translations or editing of major works within academic standards"
	Journal articles, conference proceedings, book chapters, monographs/ books, artefacts, prototypes
"Does the type of funding influence research results – and do researchers influence funders?" (Hove, 2020)	Peer-reviewed journals, reports, presentation slides
"Knowledge network of scientific claims derived from a semantic publication system" (Marcondes, 2012)	"full-text papers, algorithms, datasets of scientific data, terminological knowledge bases, and virtual machines that can process these data"
"Types of research output profiles: A multilevel latent class analysis of the Austrian Science Fund's final project report data" (Mutz et al., 2012)	"journal article, book, conference contribution, patent, software, Internet publication, and so on"
	"publication, other research output, collaboration, communication, exploitation, recognition, staff development, further funding, and impact"
	"publication (peer-reviewed journal article; non-peer-reviewed journal article, monograph, anthology, mass communication, i.e. any kind of publication in mass media, e.g. newspaper article), conference contribution (invited paper, paper, poster), award, patent, career development (diploma/ degree, PhD dissertation, habilitation thesis) follow-up project"

* Identified by forward/ backward search

Besides specific types of research results, we identified more general descriptions of research results such as *"“outputs” of university research are codified in different forms, varying over time and across industries"* (Bakouros and Samara, 2010) or *"publicly verifiable outcomes which are open to authentication and scrutiny by experts"* (European Commission, 2010). Similarly, (Mutz et al., 2012) describe *"research outputs, as the products generated from research, include the means of evidencing, interpreting, and disseminating the findings of a research study"*.

4.1.2 Classification Models Described in the Literature

Table 2 provides an overview of the classification models we identified by the systematic literature review.

Table 2. Different classification models for research results described in the literature

Literature	Classification models
"Analysing the economic payoffs from basic research" (David et al., 1992)*	"Three kinds of social benefits attributable to the results of basic research projects[:] First, information from basic research discoveries may be applied directly to the creation of new processes or products. Second, research outcomes may produce information that is an input into other basic and applied research activities and, with modification and refinement, forms the basis for new products or processes. Third, research outcomes may provide the information to improve processes or products that are primarily based on other scientific or technological discoveries"
"A bibliometric approach for department-level disciplinary analysis and science mapping of research output using multiple classification schemes" (Gautam Pitambar, 2019)	"Essential Science Indicators (ESI) 22 research fields, SCOPUS 27 subject areas, OECD Frascati 38 subordinate research fields, and KAKEN-L3 66 subject categories"
"A framework for a research inventory of sustainability assessment in manufacturing" (Lee and Lee, 2014)	e.g., MERIL (Mapping of the European Research Infrastructure Landscape) with 8 scientific domains and 71 categories (Janssen et al., 2013)
	5-level classification scheme for Sustainability Assessment in Manufacturing with the criteria for classification "Product Life Cycle […] and Organizational Unit, […] Three Pillars of Sustainability […] and Sustainability in Manufacturing Components, […] Assessment Process, […] Level Of Technology (LOT) and Use Of Technology, […] Purpose Of Assessment […] and Presentation of Assessment Result. […] LOT indicates the maturity level of the paper's particular method in terms of technology. […] The values of LOT are Research (R), Technology Development (TD), System Development (SD), and Deployment (D)"
"Aspects to be considered when making innovation out of promising research results in surface technology" (Leisner and Johansson, 2019)	Technology Development with high uncertainty/ risk but low necessary resources (funds), Technology Integration with lower uncertainty/ risk but higher necessary resources (funds), Product Development Projects with the lowest uncertainty/ risk but high necessary resources (funds). The first two phases are characterized by the technological risk and the last by the economic risk.
	Technology Readiness Level (TRL)
"Technology Readiness Levels" (Mankins, 2009, 1995)*	"TRL1: Basic principles observed and reported", "TRL 2: Technology concept and/or application formulated", "TRL 3: Analytical and experimental critical function and/or characteristic proof-of-concept", "TRL 4: Component and/or breadboard validation in a laboratory environment", "TRL 5: Component and/or breadboard validation in relevant environment", "TRL 6: System/sub-system model or prototype demonstration in a relevant environment", "TRL 7: System prototype demonstration in the expected operational environment", "TRL 8: Actual system completed and "qualified" through test and demonstration", "TRL 9: Actual system "flight proven" through successful mission operations"

* Identified by forward/ backward search

While many contributions discuss bibliometric classifications of scientific publications such as journal papers or conference proceedings only, some discuss the classification based on the "readiness" or maturity of the technology. Furthermore, one contribution classifies research results based on their social benefit impact.

4.2 Classification Models Used by the (German) Research Community

To complement the classification models described in the literature, we researched the classification models used within the German research community by contacting the institutions, as shown in Table 3:

Table 3. Classification models used in German research institutions and research community

Research institution/ community	Classification model
Karlsruhe Institute of Technology (KIT)	TRLs (European Commission, 2015))

Fraunhofer society	Unspecific, not systematically
Helmholtz Association	TRLs, for technology-related results only
acatech	Unspecific, not systematically
German Federal Ministry of Education and Research	Unspecific, not systematically

4.3 Interim Conclusion

Based on the results presented in Chapter 4.1.1, we identified five clusters of research results: *publications*, *prototypes*, *equipment*, *data*, and *experience*. The list of types of research results within these clusters cannot be conclusive due to the broad range of scientific disciplines. Thus, the literature only provides examples of results, too. The cluster *publications* contains results that are produced to get published. It contains results such as peer-reviewed and non-peer-reviewed journal articles and conference papers, monographs, book chapters, anthologies, mass communication, reports, thesis (master, bachelor, PhD/ doctoral, habilitation), patent, poster, presentation, audio, and video. The cluster *prototypes* contains results that aim to demonstrate and validate findings. These results are not limited to physical elements. Exemplary types of results within this cluster are prototypes, technical drawings, designs, algorithms, software, audio, video, and terminological knowledge base. The cluster *equipment* summarizes the results generated for further use in research, such as equipment and instruments. The cluster *data* contains the results of scientific measurements/ observations. One exemplary type of research result is a dataset of scientific data. *Experience* is a cluster containing results connected to humans. Exemplary types of results are: educated and trained scientist (master, bachelor, Ph.D./ doctoral, postdoc), staff development, recognition, impact, network of scientific and technological capabilities, and social network for information diffusion.

Analyzing the classification models presented in Chapters 4.1 and 4.2, it becomes obvious that there are no general classification models that encompass all types of research results and classifications regarding the subject area and readiness level/ maturity simultaneously. The models are either focused on journal papers/ conference proceedings only (Lee and Lee, 2014) or neglect the subject areas and do not explicitly distinguish different types of research results, such as the technology readiness levels. Furthermore, the concept of technology readiness levels is technology-focused only and neglects other results, such as design methods.

5 Initial Classification Model

Based on the findings presented in Chapter 4, we derived the first version of a research results classification model that encompasses both the subject specificity and the maturity in the sense of social benefit of research results. Furthermore, we integrated the different types of research results into the classification model. We present the model in Chapter 5.1. In Chapter 5.2, we test the model initially, using four exemplary research projects and their results.

5.1 Initial Research Results Classification Model

We designed the classification model based on the TRLs as explained above and included the variability of the different subject areas of research, as illustrated in Figure 4. We decided to take the TRLs as a reference, as this concept is widely accepted in assessing the maturity of technologies and was evolved constantly (cf. (European Association of Research and Technology Organisations, 2014; Heder, 2017; Revfi et al., 2020)). Concerning the diverse fields of study and types of research results, we generalized the technology-focused definitions of the nine TRLs and now introduce nine research readiness levels (RRL):

Research readiness level 1 - Basic principles observed and reported: RRL 1 covers results of the lowest maturity level. These are data from observations and reporting of basic principles. Thus, RRL 1 covers, e.g., data on the mechanical behavior of material systems, data from qualitative interviews, observations/ measurements of physical effects, etc. The results of RRL 1 can be the starting point for research of RRL 2 or used for validation activities of research at higher levels.

Research readiness level 2 - Concept and/or application formulated: Usually based on findings of RRL 1, RRL 2 covers, e.g., theories, concepts, or descriptions of possible future applications and represent hypotheses. The results of the second level are not yet proven but somewhat speculative at this point.

Research readiness level 3 - Analytical and/ or experimental verification of critical function and/ or characteristic: RRL 3 contains research results with analytically or experimentally verified critical functions or characteristics. These are verified individually. For example, mathematical or software engineering-based concepts might be verified analytically, while, e.g., mechanical designs or material fracture models might have to be tested physically in experiments. This verification is usually done in a laboratory environment.

Research readiness level 4 - Isolated validation in a laboratory environment: On RRL 4, the critical functions and characteristics are validated as a whole, including their interactions with each other. Results of RRL 4 are still validated in a laboratory environment.

Research readiness level 5 - Isolated validation in a relevant environment: In contrast to RRL 4, results of level 5 have to be validated in a relevant environment. However, this relevant environment can still be (partially) simulated.

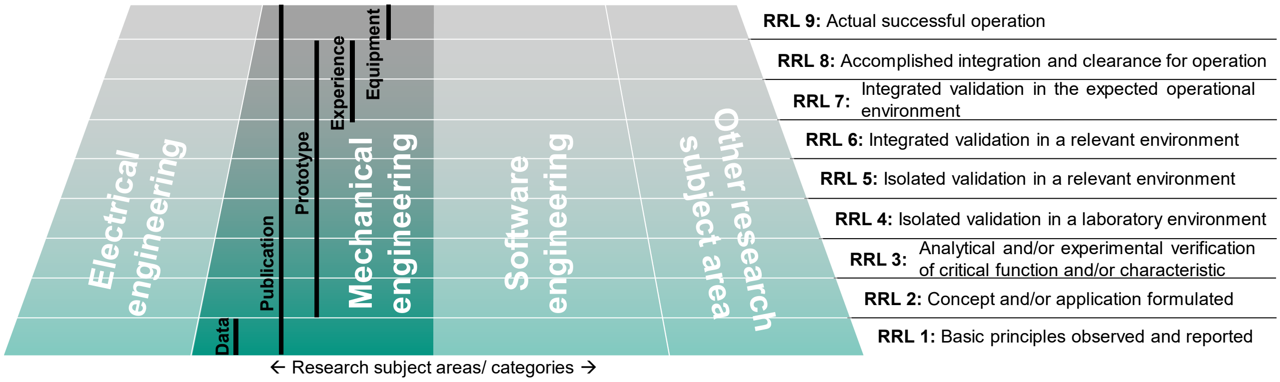

Figure 4. Initial research results classification model

Research readiness level 6 - Integrated validation in a relevant environment: In case different research results shall be combined/ integrated with each other or already existing elements, these have to be validated as a combined system in a relevant environment to reach RRL 6.

Research readiness level 7 - Integrated validation in the expected operational environment: In contrast to RRL 6, results of level 7 have to be validated in the expected operational environment.

Research readiness level 8 - Accomplished integration and clearance for operation: RRL 8 is a rather formal level of research results that achieved the clearance for "regular" operation in the intended environment. Depending on the research, clearance by external entities might be required.

Research readiness level 9 - Actual successful operation: RRL 9 contains results that are successfully operated in their final environment. Since research facilities usually do not directly offer "products" or "systems" to society, these results will usually be operated within the research itself. For example, the test benches to be used for validation/ characterization activities (e.g., to achieve RRL 5 for another research result) could be such results of RRL 9. However, research facilities might offer services such as qualification programs or technical systems such as test facilities to society or companies.

The researchers must conduct validation activities to advance in the maturity level. Therefore, we want to stress the relevancy of results of RRL 1 as "simple data" is often the basis for validation activities and thus crucial for the advancement in maturity level. However, not all results will climb the maturity levels step by step. Research is often characterized by trial and error. Thus, some research results will directly be established on a higher RRL.

Within the model, we allocated the five clusters of different types of research results to the RRLs. Publications can be made describing (other types of) results on all levels. Data, prototype, and equipment complement each other. Data itself can only represent results on RRL 1 since data is only a set of observations or measurements. However, it can be generated and used during the validation of other results of higher levels. Prototypes span from RRL 2 to RRL 9. On all these levels, the types of results of the cluster prototype play an essential role. All intermediate results of levels two to nine are prototypes or descriptions of these within publications in a way. We allocated the cluster equipment to RRL 9 since equipment contains the types of results used during other research activities. Finally, we allocated the cluster experience to the RRL 8 and 9. With their qualification exams/ theses, the educated people are of level 8 while the (social) networks are in operation and thus of level 9.

5.2 Initial Validation of the Initial Research Results Classification Model

For an initial validation of the classification model, we gathered the results of four research projects of different engineering disciplines via an interview study. These projects are 1.) *design method in computer-aided engineering for shape and topology optimization of composite material parts (LFT-D - Long Fiber Thermoplast Directmolding)*, 2.) *processing and production of composite parts in LFT-D processes*, 3.) *characterization of LFT-D composite material systems*, and 4.) *viscoelastic modeling and simulation of LFT-D composite material systems*.

In the first project, the researcher produced i.a. the following results: *Optimization procedure* (coupling model) of optimization and design tools implemented on a workstation (prototype), illustrated on slides, and publicized in conference publications (**RRL 2-6** since the procedure was further developed in iterative steps and intermediate states of the result produced). Scripts to couple different simulation and design tools programmed in Python code and published in conference publications (**RRL 7** since it is integrated into and validated within the optimization procedure). *New optimized designs*, as results of the optimization procedure to validate the quality and function of the optimization procedure as CAD parts (**RRL 1** since the parts by themself are only data that serve for validation of other results).

In the second project, the researcher produced i.a. the following results: *Influences of fiber bundles* and their appearance during the molding process on material quality published in conference publication and visualized on a material prototype (**RRL 3** since the concept of the influences was validated via prototyping). *Recommendations for quality management* and assessment for machinery manufacturers published at conferences (targeted result; **RRL 7** since the result shall be validated on the commercial machinery used by the researcher). *Monitoring technology* to monitor the quality of the produced parts published at conferences and demonstrated by a prototype (targeted result; **RRL 6** since it is not planned to integrate the monitoring technology into the machinery during the project). *STL-Files (images)* of plastificat published in journal publications and stored on server (**RRL 1**). *Seminars* on the processing for practitioners (**RRL 9** since the seminars are already offered).

In the third project, the researcher produced i.a. the following results: *Data representing material properties* (tensile, impact, bending, creep testing) published in journal and conference publications (**RRL 1** since the result is data). *Modeling approaches/ hypotheses* for material behavior description publicized in a journal publication and on a server as a prototype (**RRL 4** since the models are validated in a laboratory environment). *Images of microscopy* on fiber orientation publicized in a journal publication and on a server (**RRL 1**). *Scripts for data analysis* (**RRL 9** since this result is used during the research).

In the fourth project, the researcher produced i.a. the following results: *Mathematic model* (differential equations) including the material parameters for viscoelastic modeling of, e.g., polyamide (PA) published in a journal publication and implemented on a workstation (prototype) (**RRL 4** since the model is validated in a laboratory environment using experimental data). *Exemplary material parameters* (diagrams) for load case behavior considering different moistures publicized in a journal publication and on a server (**RRL 2** since the diagrams represent the estimated behavior of the material system).

In all projects, the researchers supervised bachelor and master students doing their theses and themselves aimed at completing their doctoral theses. Thus, they gathered know-how and experience and set up networks (**RRL 8** and **9**).

6 Discussion

We designed the research results classification model in a way to enable the categorization of research results of different scientific disciplines regarding their maturity. Our primary focus is on engineering sciences. Thus, we have considered these disciplines in this submission. To quantify the maturity, we introduced the idea of research readiness levels. Here, the maturity of research results means the "distance to societal benefit". A higher maturity level means that the results are closer to providing a benefit to society. In engineering, universities usually do not offer directly to society, but companies will integrate the research results into their offers. Examples are technological results such as a new lightweight material implemented into products offered to society. However, this is also valid for results such as design methods or regarding process development. Companies use such research results to improve their engineering or, e.g., offer new engineering methods to their business customers. Thus, via companies, society benefits from research results on a high research readiness level either directly (e.g., in the case of technological results) or indirectly (e.g., in the case of methodological results or results used within the research itself). Universities and other research facilities do not do research alone. Companies and even society (as the final customer) are often involved and cooperate within the research project. Exceptions are results such as research equipment. Researchers include companies and society in higher RRLs more intensively, especially if they are researching technologies. However, especially in design research (researching the design process as defined by Blessing and Chakrabarti (2009)), the consideration of real-world environments and requirements (corporate or societal) is crucial from the beginning.

As presented in Chapter 5.2, we did a successful initial validation of our classification model as we could assign the different research results to the different research readiness levels. Of course, this validation is only an exemplary initial test of our first version of the research results classification model. Due to the high variability of research and its results, a way broader validation study would be necessary to validate the model comprehensively. However, we still believe that this model provides a starting point for the discussion of classifying research results regarding its maturity and its relation to societal benefit. We also believe that an adjusted understanding of our model will enable the classification of research results of other scientific fields beyond engineering, too. Thus e.g., we expect a fractal character of our model to include natural sciences such as physics. While, from an engineering perspective, physics operates on the RRLs 1 and 2, from a physics perspective, they also climb in the readiness levels, offering, in the end, to other scientific disciplines.

7 Conclusion and outlook

An understanding of the different types of research results is the basis for effective knowledge and technology transfer from research to corporate product engineering. Based on our systematic literature review, we discovered that no comprehensive collection of different possible types of research results exists for engineering disciplines, not to speak of all research and scientific activities. This is mainly due to the wide range and diversity of "research" and, thus, the individuality of research results. We only identified six publications regarding the types of research results. One reason for this low number might be our focus on titles and keywords in this search. However, due to the structures of abstracts, the inclusion of abstracts into the search does result in non-feasible numbers of search results. However, we believe that publications focused on the investigation of research types will indicate this in their titles or keywords, too. Thus, we conclude that current research does not focus on the different types of research results and their characteristics. First, the lack of classification models for research results in the literature supports this conclusion. Second, this conclusion is also supported by the lack and deficiency of established classification models/ approaches in the (German) research community (e.g., universities and other research facilities). Due to the focus on German entities only, we cannot generalize our findings internationally. However, we believe our selection of leading German research facilities and research societies (with a focus on engineering) is somewhat representative.

So far, the classification of research results only considers the scientific area/ discipline but does not differ regarding different types or characteristics within the discipline. Some first approaches try to utilize the understanding of technology readiness levels. However, TRLs are also too narrow (technology-focused) to appreciate the diversity of even the engineering disciplines in research. We propose the presented initial research results classification model to overcome the present shortcomings. With its broader definitions of research readiness levels (RRLs) based on TRLs, we offer a starting point for targeted research in the field of technology and knowledge transfer from research to corporate application. Our research aims to start the discussion of classifying research results in the field of engineering and perspectival beyond. So far, the presented model is only an initial classification model. In future research, we aim to evolve and validate the model further. However, we believe that the systematic classification and description of research results using the research readiness levels enables the research and development of specific design support that will enhance corporate engineers' use of research results as reference system elements. Such support will help corporate engineers to integrate research results into their engineering activities more effectively. In the next step, we will research the specifics of using research results on different RRLs in corporate product engineering. Finally, based on these findings, we intend to develop concrete recommendations addressing research and industry to improve the usability of different research results as RSEs.

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